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ENGINEERING EVALUATION OF THE PRE-STRESS/ SURFACE REMOVAL TECHNIQUE FOR FATIGUE OR CREEP ENHANCEMENT

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13. ABSTRACT

Compressor blades of annealed Ti 6Al-4V alloy were step fatigue tested in the fundamental mode to determine the effect of a prestress-surface stress removal treatment on the 10^7 cycle fatigue strength. Prestressing the blades in axial tension at 80-100 ksi and stress relaxing at ambient temperature, improved the average 10^7 cycle fatigue strength up to 60%. Residual surface stresses on the blades, measured before and after prestressing, showed a residual compressive stress due to prestressing. Glass bead peening failed to improve the annealed blade fatigue strength. Practical methods for prestressing blades must be developed for production application of this process.

The prestress-surface stress removal treatment was not effective in reducing the secondary creep rate of cast nickel base MAR-M246 alloy material at realistic turbine blade temperatures and stresses.

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The prestress-surface stress removal treatment was not effective in reducing the secondary creep rate of cast nickel base MAR-M246 alloy material at realistic turbine blade temperatures and stresses.

FOREWORD

This final report describes the work completed by Detroit Diesel Allison (DDA) Division of General Motors Corporation during the period June 14, 1972 to June 15, 1973 on the, "Engineering Evaluation of the Prestress/Surface Removal Techniques for Fatigue or Creep Enhancement". This work was performed for the Department of the Navy, Naval Air Systems Command (NASC) under Contract N00019-72-C-0456, with Mr. R. Schmidt as NASC technical monitor. E. S. Nichols, Senior Experimental Materials Engineer and G. R. Sippel, Section Chief - Advanced Materials Research were the DDA project engineers for the program. Fatigue testing was conducted under the direction of B. G. Veerkamp and creep testing under T. C. Tsareff, Jr. Dr. M. Herman, Chief - Materials Research, acted as consultant and advisor on the program.

1.0 INTRODUCTION

The objective of this program was to evaluate the engineering significance of the prestress/surface removal treatment for enhancement of creep and fatigue by determining if it can be successfully applied to real or simulated hardware. This treatment, which consists of prestressing below the proportional limit followed by surface layer elimination by chemical or thermal means, has previously been shown by I. R. Kramer and others of the Martin Marietta Corporation to improve fatigue and creep behavior of laboratory specimens of certain materials.[1, 2, 3, 4]

The work in the current program was divided into two tasks. The first is concerned with fatigue investigations using annealed Ti 6Al-4V compressor rotor blades and the second deals with the creep behavior of cast nickel base turbine blade alloys.

2.0 FATIGUE STUDIES

A Ti 6Al-4V first stage compressor blade from an early development compressor, was selected for fatigue studies in this program. A drawing of the blade, P/N EX 84093, is shown in Figure 1. This blade was originally solution heat treated and aged, followed by glass bead peening. Since the fatigue improvement of Ti 6Al-4V, by prestress-surface removal treatment, was originally shown by Kramer and Kumar[1] on annealed test bars, the blades for evaluation in this program were vacuum annealed at 1300F for two hours prior to any prestressing or testing.

2.1 Fatigue Stress Survey

Prior to the fatigue test, three of the blades were calibrated in first bending mode with five strain gages located at midchord suction side at the following positions above the platform: .06, .31, .56, .81 and 1.06 inch. A calibration curve of the relative stress level at these five locations for each of three blades is shown in Figure 2. In each case the highest stress was indicated by the strain gage located .31 inch above the platform and up to about 10 percent higher than the strain gage located .06 inch above the platform.

2.2 Prestress-Surface Stress Removal Procedure (SSR)

The work performed by Kramer and Kumar[1], on the effect of prestressing and surface removal on the fatigue properties of annealed Ti 6Al-4V, showed that a prestress of 100 ksi prior to surface stress removal, increased the fatigue endurance limit stress by 8 ksi (77 to 85 ksi). A method was developed for gripping the airfoil and axially prestressing the lower portion of the airfoil to 100 ksi, where the highest fatigue stresses would occur in the first bending mode. The gripping arrangement consists of a thick glass cloth-epoxy layup on the blade airfoil extending from 1/8 in. above the airfoil-platform radius at the trailing edge to a point 2 inches beyond the blade tip. The glass-epoxy extension at the tip is gripped by wedge jaws and the base of the blade pin loaded in a tensile machine to the desired prestress-load. Pin-clevis joints are used at both ends of the loading train to maintain axial blade loading. A laid-up blade after successful prestressing is shown in Figure 3.

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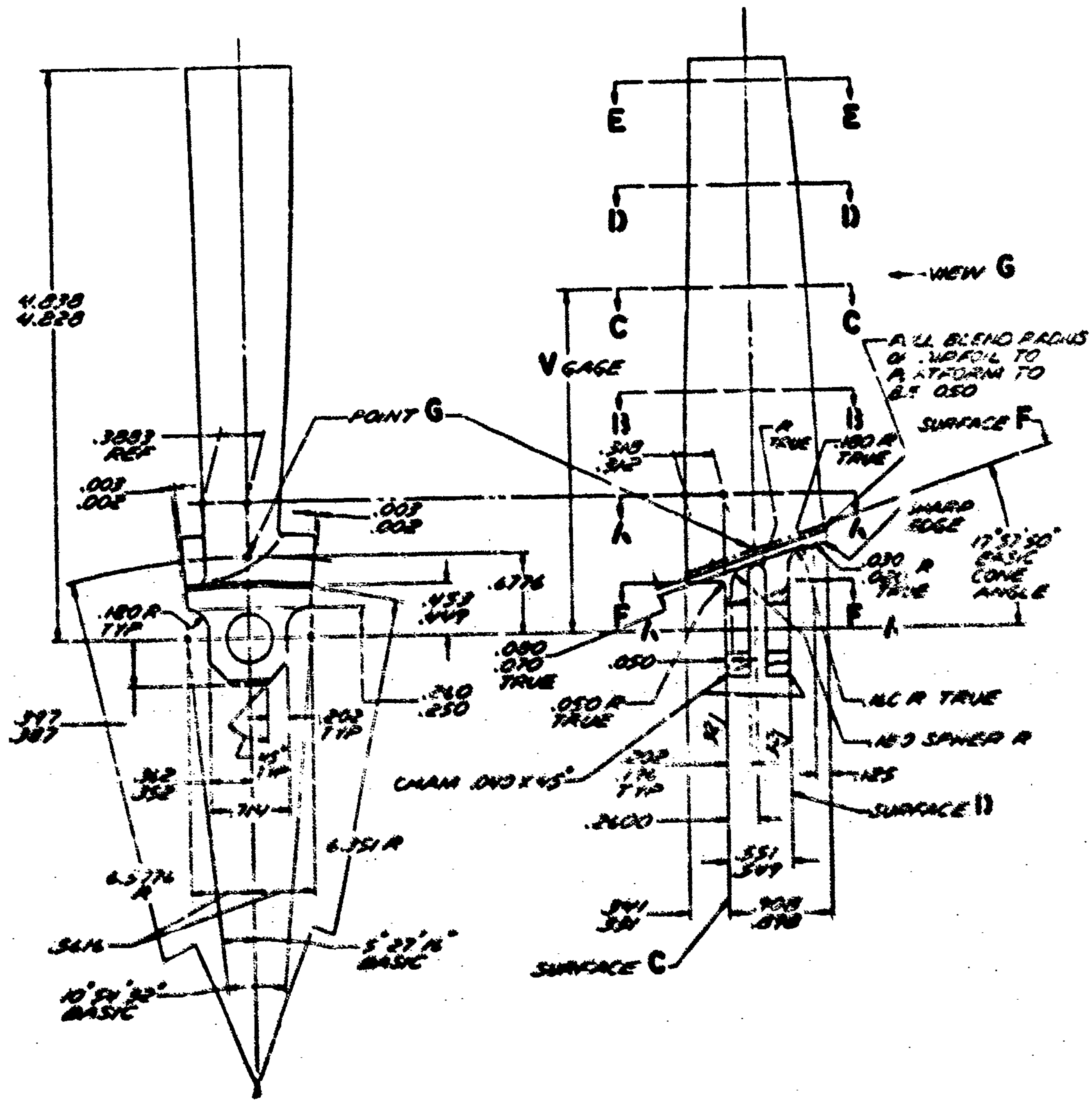

Figure 1. First stage compressor blade P/N EX 84093, annealed Ti 6Al-4V material.

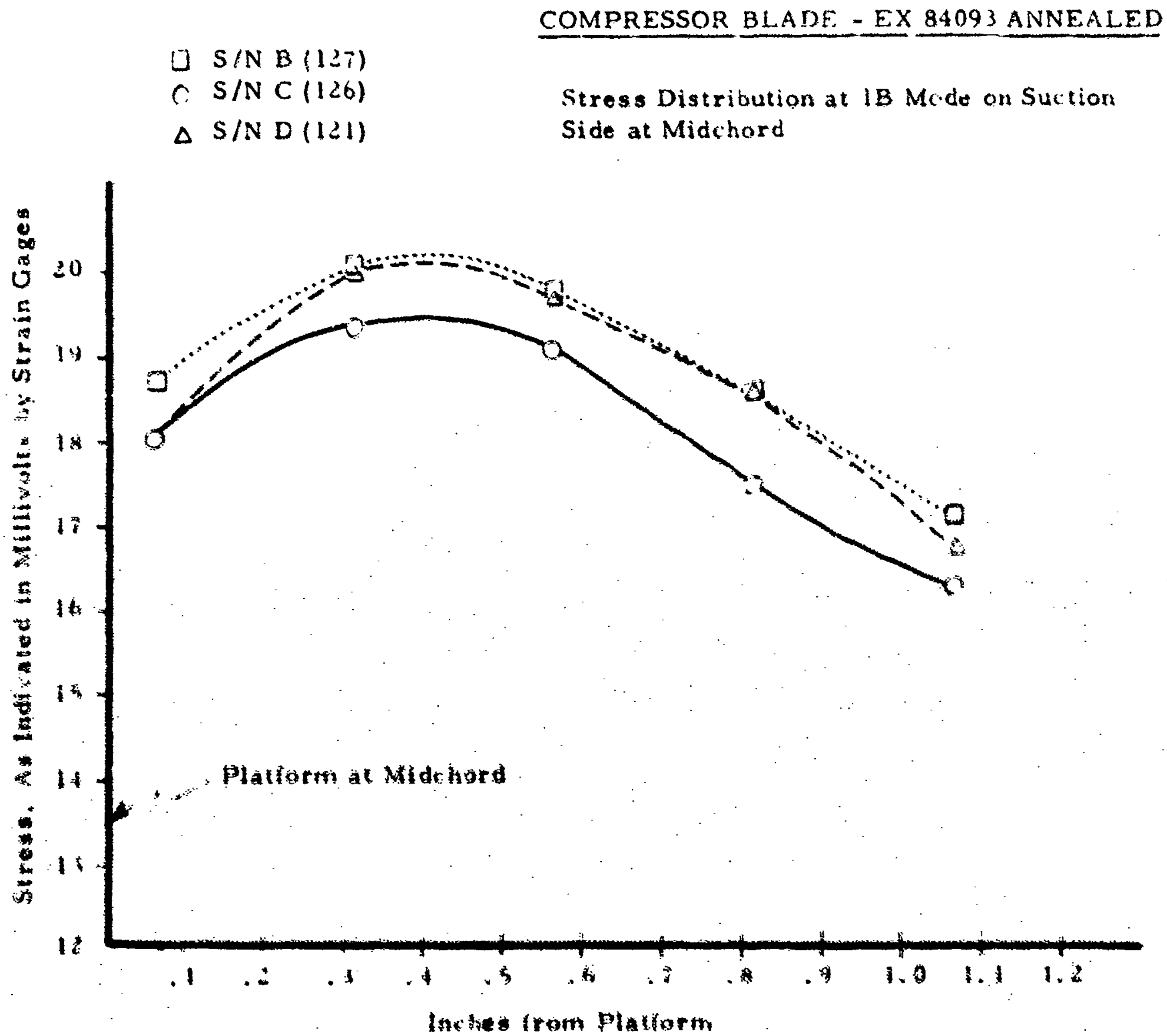

Figure 2. Stress distribution in first bending mode on suction surface at midchord.

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Figure 3. Typical blade after prestressing to 11,750 pounds, showing glasscloth-epoxy layup used to grip airfoil.

2.2 Prestress-Surface Stress Removal Procedure (Cont'd)

Two blades were instrumented with strain gages located on the pressure and suction surfaces at midchord just above the airfoil-platform fillet, as shown in Figure 4. These instrumented blades were used to determine the axial load required to produce 100 ksi stress in this portion of the airfoil. Figure 5 shows the load-strain curves for blade S/N 135 and indicates that a strain of 6250 microinches (100 ksi in 16×10^6 psi modulus Ti 6Al-4V) is reached on the suction surface at a load of ~11,400 pounds. Blade S/N 89 required a load of 11,750 pounds to produce this same strain of 6250 microinches on the suction surface. Based on the close agreement of these two blades in load-strain response, all blades requiring prestress were loaded to 11,750 pounds in four minutes, held at load one minute and unloaded. This prestress treatment produced a midchord stress of 100 ksi on the suction surface and 83 ksi on the pressure surface in the lower portion of the airfoil where fatigue failures occur in first bending mode.

A total of six blades were laid-up for prestressing and fatigue testing. The surface stress removal after prestressing was accomplished by stress relaxation at room temperature for a minimum of 100 hours. The endurance limit improvement for annealed Ti 6Al-4V in Reference 1 was accomplished by overnight room temperature stress relaxation after 100 ksi prestressing.(2)

2.3 Residual Surface Stress Analyses

Eight annealed Ti 6Al-4V compressor blades, P/N EX 84093 were analyzed for surface residual stress by X-ray diffraction measurements. The area analyzed was at the midchord suction surface, just above the air-foil-to-platform fillet. High and low residual stress blades were reanalyzed for residual stress after prestressing and surface stress removal, prior to fatigue testing.

The results of the residual stress measurements in Table I, show that the as-annealed blades contained residual surface stresses ranging from -3.9 ksi to +27.5 ksi. After prestressing and surface stress removal, all blades measured show compressive residual stresses ranging from -15.7 to -38.4 ksi, regardless of the initial stress level. These data indicate that the prestress-surface stress removal treatment removes any tensile residual surface stresses and replaces them with modest compressive stresses, which should be beneficial to fatigue life.

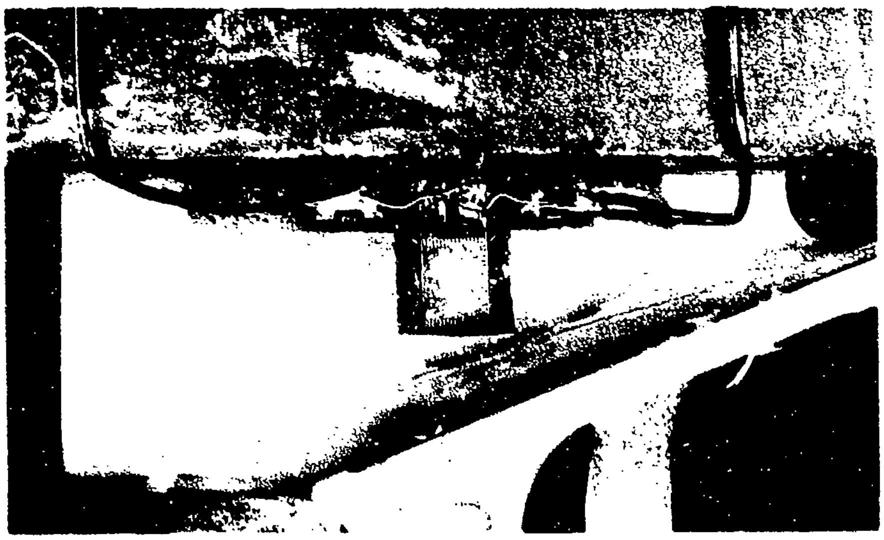

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Figure 4. Blade S/N 135 showing strain gage location at midchord above platform for prestressing calibration.

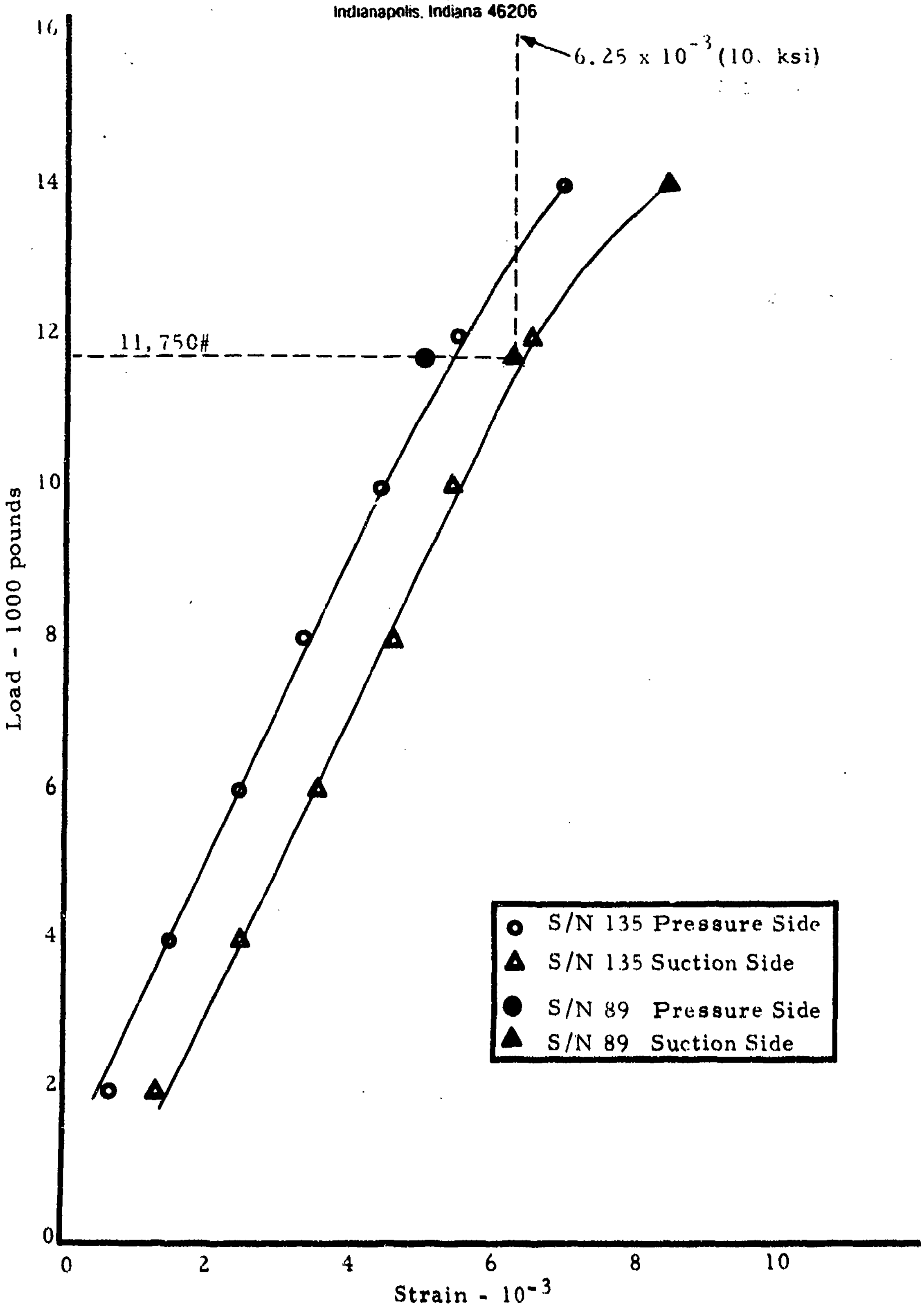

Figure 5. Load-Strain Curves for prestressing blades P/N EX 84093 (Ti 6Al-4V Annealed).

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TABLE I

X-Ray Diffraction Residual Surface Stress Measurements on Annealed Ti 6Al-4V Compressor Blades P/N EX 84093

Serial No.	Residual Stress - ksi (1): As-Annealed	Residual Stress - ksi (1): Prestress + SSR (2)
135	- 3.9	N.A.
84	- 7.6	-16.2
73	+ 7.3	N.A.
89	+12.9	N.A.
64	+17.4	N.A.
98	+20.6	N.A.
42	+25.4	-38.4
7	+27.5	-15.7

(1) Convex Surface — Midchord just above airfoil-platform fillet

(2) Prestress 100 ksi + room temperature stress relaxed >100 hrs.

N.A. - Not analyzed

2.4 Fatigue Test Procedure

The blades were clamped in a vise at the clevis type attachment below the platform during the fatigue test. The airfoil was excited to vibrate in the fundamental or first bend mode (~360 Hertz) by means of an air jet directed at the tip of the blade.

During the fatigue test the relative vibratory stress level was determined by the stress reading from the strain gage at the position .06 inch above the platform at midchord suction surface. On each 10^7 cycle step of the fatigue test, the alternating stress value was increased approximately ±10,000 psi. Relative fatigue strength was determined by interpolating between the stress level at which the last 10^7 cycle step was completed and the stress level of the step at which failure occurred, according to the following formula:

$$\text{Fatigue Strength} = \sigma_a + X(\sigma_b - \sigma_a)$$

where σ_a is the alternating stress indicated by strain gage at the .06 inch position on the last 10^7 cycle completed, σ_b is the alternating stress indicated by strain gage at the .06 inch position on the step on which failure occurred, and X is determined from the following table.

Percent of 10^7 Cycles Completed	X
0 to 5%	Zero
5 to 20%	20%
20 to 50%	50%
50 to 100%	80%

Five annealed blades were calibrated for blade tip displacement vs. strain gage out put. The correlations were linear and nearly identical for the blades tested. The blade tip displacement was used to set and monitor the alternating stress levels during the tests through this displacement-strain gage output calibration. The five blades showed an average calibration factor of ±93.2 ksi/inch tip displacement with a standard deviation of 1.9. This factor was used in all subsequent blade fatigue tests.

2.5 Fatigue Test Results and Analysis

A total of five annealed blades and six prestress-surface stress removal processed blades were fatigue tested. Two additional annealed blades were tested early in the program but failed on the first step and therefore are not included in the analysis, since a 10^7 cycle fatigue stress cannot be calculated for these blades.

The fatigue test results in Table II, show a significant improvement in the average 10^7 cycle fatigue stress due to the prestress-surface stress removal treatment, with an average of 58.[illegible] ksi compared to 47.3 ksi for the annealed blades. A Student's t test analysis of the data showed a 95% probability of a significant difference between the 10^7 cycle fatigue strengths of the two groups of blades.

The 23% improvement in the blade fatigue life in this program compares to 10% for test bars as reported in Reference 1. This difference in improvement may be due to one or more of the following differences in the two sets of test data.

Present Program	Reference[1]
Bending Fatigue	Axial Fatigue
Notch present-airfoil fillet	Smooth Bar

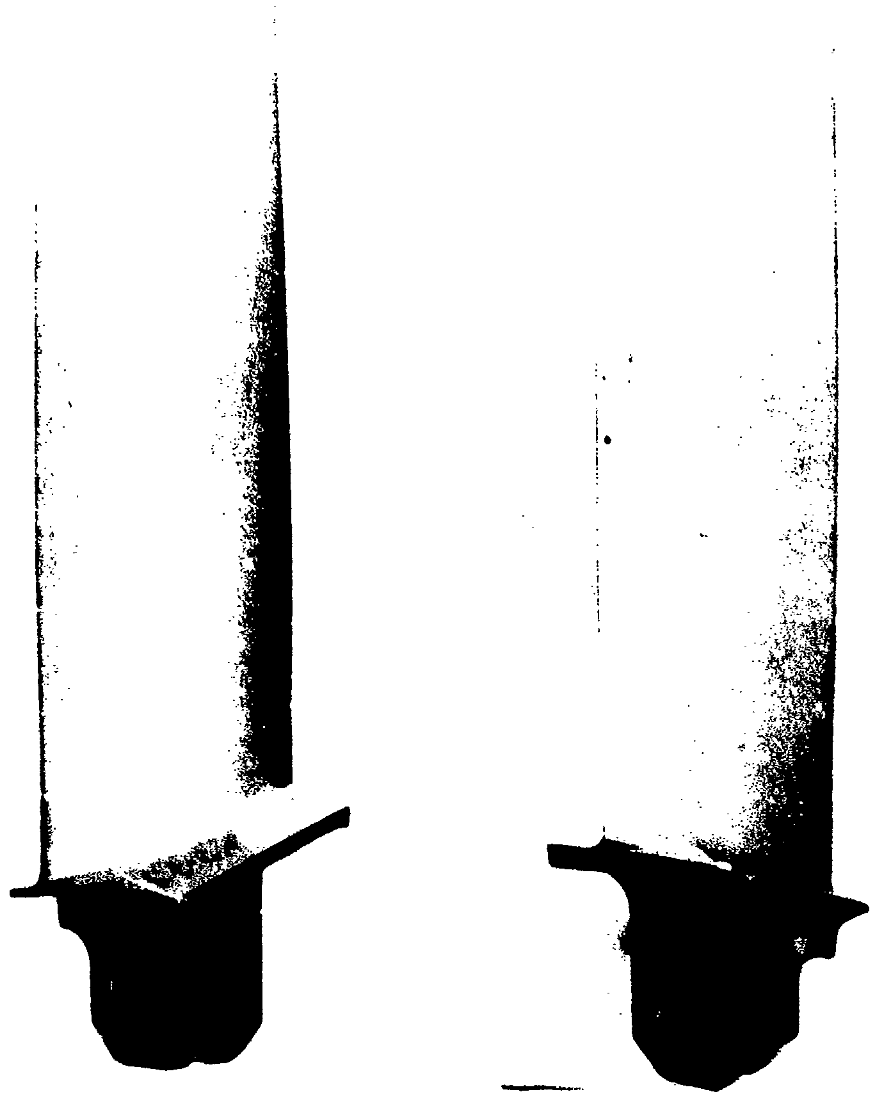
Typical fluorescent penetrant indications of fatigue cracks in an annealed and a prestress-surface stress removal blade are shown in Figures 6 and 7, respectively. Figure 8 shows typical fatigue crack fracture surfaces for the two sets of blades. All failures in both sets of blades occurred in or immediately adjacent to the radius between the airfoil and platform. The notch fatigue factor of this radius is believed to be responsible for failure initiating below the maximum stress area determined by the dynamic stress survey for the blades, reported in section 2.1 of this report. All but one of the blades showed fatigue initiation on the pressure surface in the trailing edge half of the blade chord. Annealed blade S/N 126 had fatigue initiation at the suction surface in the leading edge half of the blade chord. The predominant fatigue failure origins in both groups of blades were essentially the same, i.e., approximately 0.5 inch from the trailing edge on the pressure side at the airfoil-platform radius.

Table II

Fatigue Strength (10^7 Cycle) of
Annealed Ti 6Al-4V Compressor Blades, P/N EX 84093

As Annealed		Prestress + SSR[1]	
S/N	Fatigue Strength, ksi	S/N	Fatigue Strength, ksi
71	±41.0	73	±51.8
121	42.2	7	52.2
126	42.7	64	56.9
9	51.2	84	61.8
127	59.6	98	62.9
		42	63.1
Average	47.3	Average	58.1
Std Dev.	7.8	Std Dev.	5.3

(1) Prestressed to 100 ksi + room temperature stress relaxed >100 hours

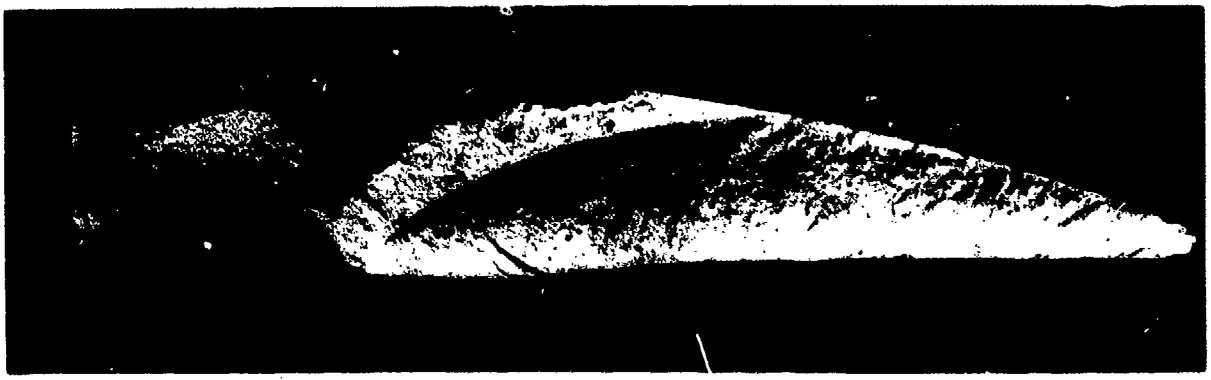


Suction Side (8-35291)   Pressure Side (8-35292)

Figure 6. Annealed Blade S/N 71 showing fluorescent penetrant indications of fatigue crack in airfoil-platform fillet at trailing edge. (Magn. 1X)

Suction Side (8-36168) — Pressure Side (8-36167)

Figure 7. Prestress + SSR Blade S/N 64 showing fluorescent penetrant indications of fatigue crack in airfoil-platform fillet at trailing edge. (Magn. 1X) (Remanents of epoxy resin from gripping layup on airfoil)



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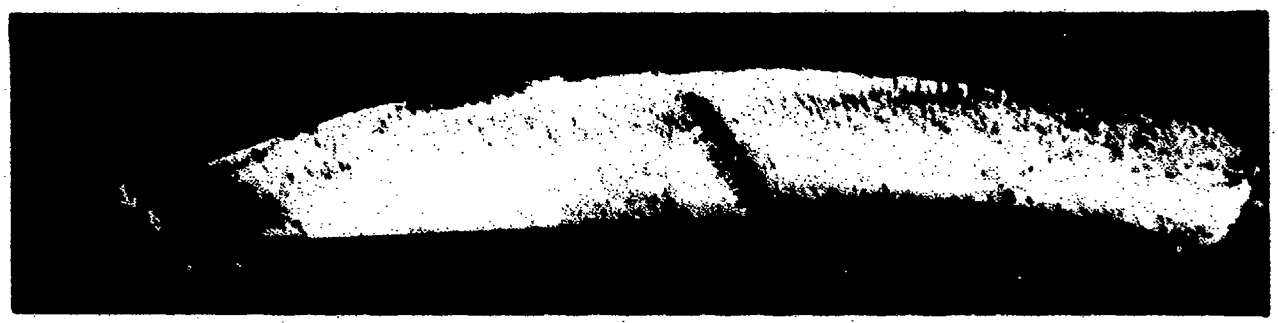
S/N 71



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S/N 64

Figure 8. Fatigue fracture surface in annealed Blade S/N 71 and pre-stressed - SSR Blade S/N 64. (Magn: 6X)

2.5 Fatigue Test Results and Analysis (Cont'd)

In order to determine if clamping of the root attachment of the blades during fatigue testing produced any appreciable static stress in blade airfoils, a radial and chordal strain gage rosette was placed on two prestressed and two non-prestressed blades, at the predominant failure origin area. The untested blades were clamped in the vise used for fatigue testing and strain readings were recorded.

The results of the clamping tests, shown in Table III, revealed that the normal blade clamping procedure produced a static compressive radial stress of -18 ksi in the failure origin area of annealed blades and a radial tensile stress of +17 ksi in the prestress-surface stress removal blades. The addition of a 0.003 inch shim to the thickness of the spacer insert, normally used to prevent distortion of the root attachment lugs during clamping, reduced the airfoil stresses in both blade groups. (The same spacer insert was used on all fatigue tested blades.) These tests show good reproducibility of the clamping stresses on the same blade and between blades in the same group. However, a significant difference was observed between the two blade groups.

The cause for this difference in clamping stresses between the groups is probably due to some root attachment deformation during the axial loading of the prestress-SSR blades to 11,750 pounds through the holes in the root attachment lugs, (~100 ksi stress at lug holes). This deformation manifests itself in a manner similar to the 0.003 inch shim used during the clamping stress tests.

The effect of a tensile or compressive mean stress on the 10^7 cycle life alternating stress for notched (K_t = 3.3) annealed Ti 6Al-4V is shown in Figure 9. The compressive mean stress part of the diagram is extrapolated from the mean tensile stress portion of the diagram. The diagram indicates that if the fatigue test results generated on the two groups of blades in this program were normalized to a zero mean stress, the 10^7 cycle fatigue strengths would be as shown in Table IV. The normalized data show a 60% improvement in 10^7 cycle fatigue strength for the prestress-SSR blades over the as-annealed blades compared to a 23% improvement based on the original test data.

Table III

Airfoil Static Stress Measurements During Clamping of Root Attachment of Blades

	Annealed				Prestress + SSR			
	Blade A		Blade B		Blade C		Blade D	
	Strain 10^{-6}	Stress ksi	Strain 10^{-6}	Strain ksi	Strain 10^{-6}	Stress ksi	Strain 10^{-6}	Stress ksi
Normal Clamp #1								
Radial	-1250	-17.8	-1305	-18.6	+ 640	+17.6	+ 460	+14.3
Chordal	+ 800	-	+ 825	-	+1200	-	+1170	-
Normal Clamp #2								
Radial	-1280	-18.1	-1240	-17.8	+ 640	+17.7	+ 460	+14.8
Chordal	+ 830	-	+ 755	-	+1220	-	+1210	-
***Shim Clamp #1**								
Radial	- 770	-11.0	- 770	-11.1	+ 470	+12.9	+ 380	+11.3
Chordal	+ 490	-	+ 470	-	+ 880	-	+ 880	-
***Shim Clamp #2**								
Radial	- 810	-11.6	- 790	-11.4	+ 470	+12.7	+360	+11.0
Chordal	+ 500	-	+ 480	-	+ 840	-	+890	-

*0.003 inch shim added to root attachment insert spacer.

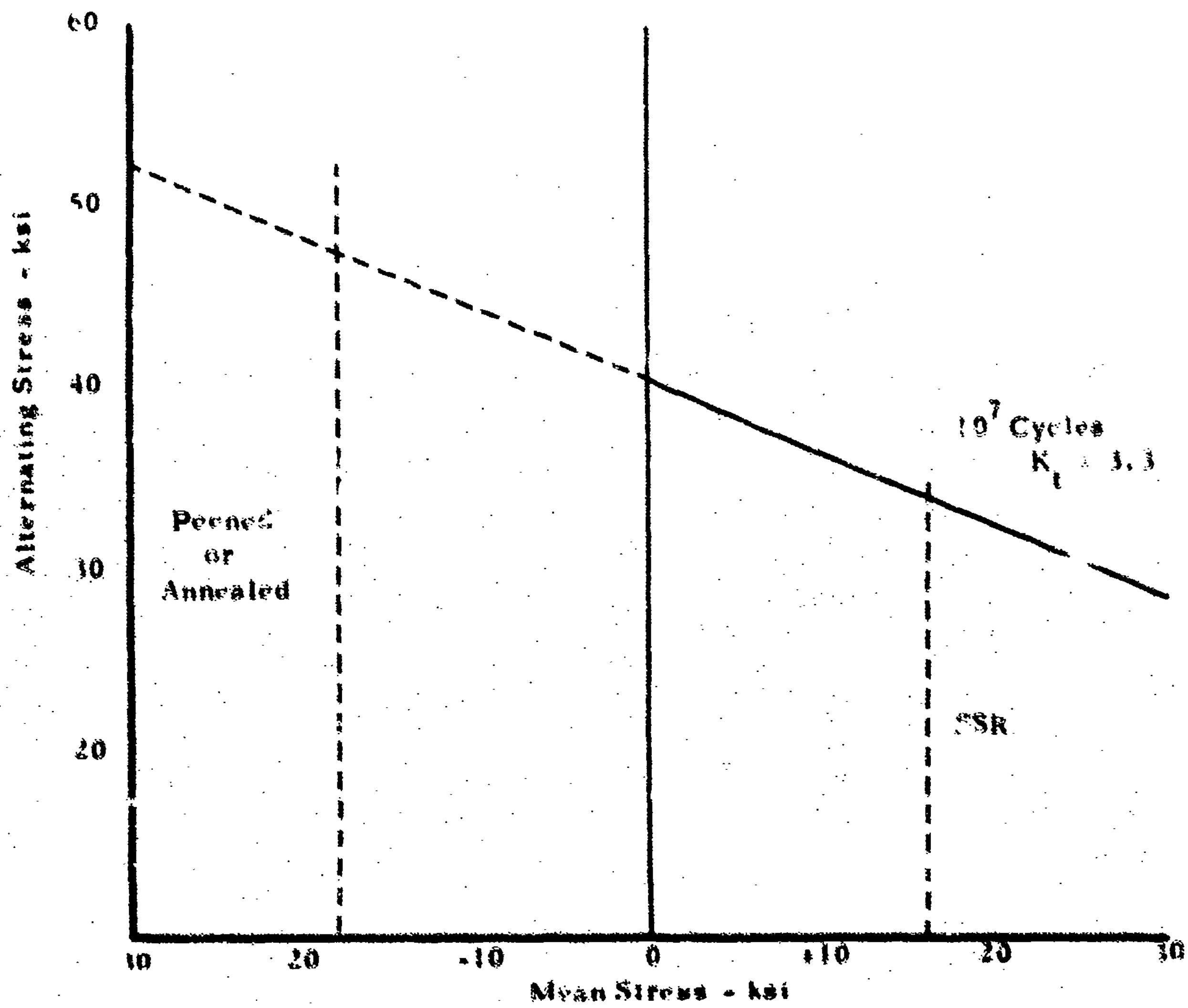


Figure 9. Modified Goodman diagram for annealed Ti 6Al-4V (MIL-HDBK-5B, 1971)

Table IV

Normalized 10^7 Cycle Average Fatigue Strengths of Annealed Ti 6Al-4V Compressor Blades P/N EX 84093

	Test Data		Normalized Data	
	Mean Stress (ksi)	Alt. Stress (ksi)	Mean Stress (ksi)	Alt. Stress (ksi)
As-Annealed	-18	±47.3	0	±40.3
Prestress-SSR	+16	±58.1	0	±64.6

2.5 Fatigue Test Results and Analysis (Cont'd)

The actual test data and the normalized data show a significant improvement in fatigue strength by prestress-SSR treatment of the Ti 6Al-4V compressor blades. The method used in this program for stressing the blades to the proportional limit, however, is not practical from a production viewpoint. The stressing of blades by overspeed spinning in a spin pit may not be practical due to root attachment and wheel stress limitations. In addition, the stressing of areas other than the lower portions of the blade airfoil by spinning is not practical, since the centrifugal stresses decrease toward the blade tip at a given rpm. The practical application of the prestress-SSR process for compressor blade fatigue improvement must await a practical prestressing method.

2.5.1 Glass Bead Peened Blades

Since the prestress-SSR treated blades showed a significant improvement in fatigue life over the annealed blades, additional fatigue tests were conducted on annealed blades after a glass bead peening treatment in order to determine if the same improvement could be obtained by peening. Six annealed blades were peened with No. 18 glass beads at 40 psi air pressure to an Almen N2 intensity of .011 inch. All surfaces of the blades, including the airfoil-to-platform radii, were peened with 100% coverage.

The fatigue strength of the glass bead peened blades was essentially the same as the as-annealed blades with an average 10^7 cycle strength of 49.0 ksi compared to 47.3 for the annealed blades, as shown by the fatigue test results summary in Table V.

The reason for the lack of improvement in fatigue strength by peening is not clear, but may have been influenced by insufficient peening intensity and/or coverage. Another possible cause might be the reduction or elimination of the high compressive surface stresses by compressive plastic deformation in the notched failure origin area, during the compression portion of the reversed bending fatigue test.

2.6 Microstructure

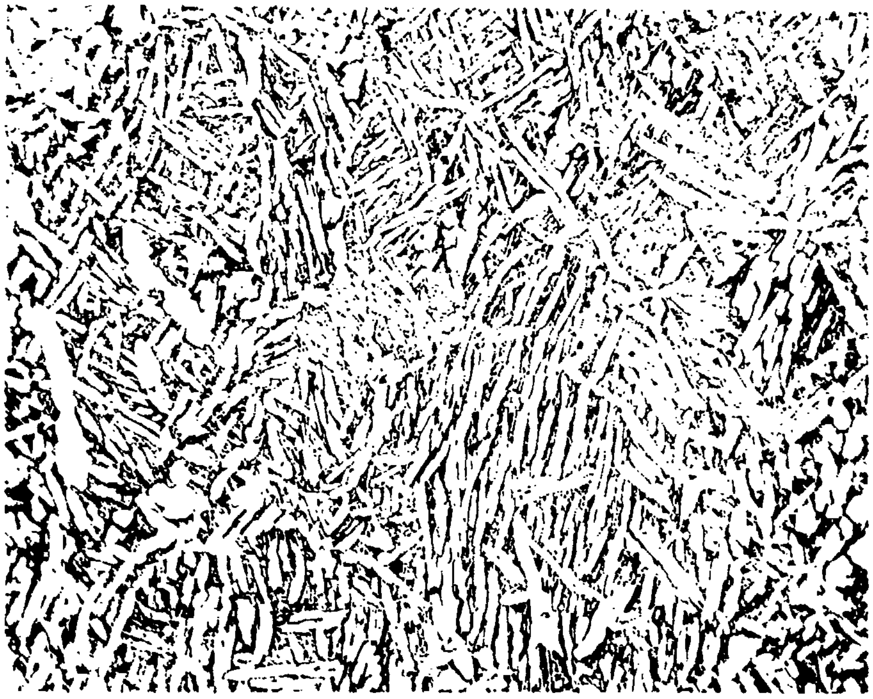
The microstructure of each blade was examined after fatigue testing. All but three of the blades showed an alpha-beta Widmanstatten structure indicative of hot working or heating over the beta transus temperature of Ti 6Al-4V as shown in Figure 10a. One blade in each of the three blade

Table V

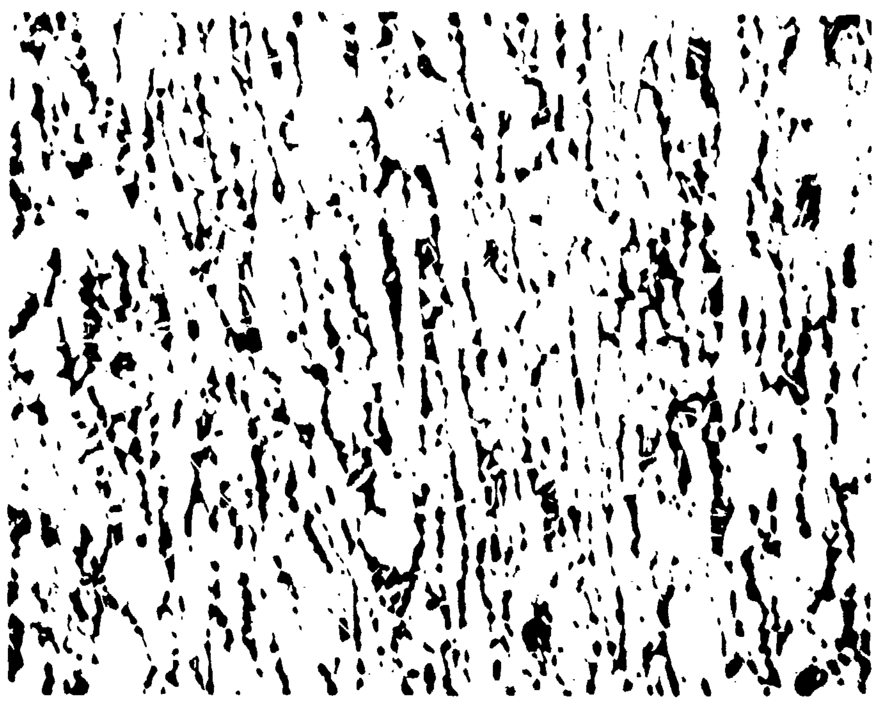
Fatigue Strength (10^7 Cycle) and Failure Location of Annealed Ti 6Al-4V Compressor Blades, P/N EX 84093

Serial Number	Fatigue Strength (ksi)	Failure Location (dist. from TE-in.)
		As-Annealed
71	±41.0	Pressure - 0.377
121	42.2	Pressure - 0.491
126	42.7	Suction- 0.900
9	51.2	Pressure - 0.302
127	49.6	Pressure - 0.575
$\overline{X}$	47.3	
σ	7.8	
		Prestress + SSR
73	51.8	Pressure - 0.440
7	52.2	Pressure - 0.516
64	56.9	Pressure - 0.407
84	61.8	Pressure - 0.516
98	62.9	Pressure - 0.505
42	63.1	Pressure - 0.500
$\overline{X}$	58.1	
σ	5.3	
		Glass Bead Peened
78	43.5	Pressure - 0.625 * Suction - 0.936 *
111	45.7	Pressure - 0.525
120	46.1	Suction - 0.809
47	47.8	Pressure - 0.500
82	55.1	Suction - 0.875
79	55.6	Pressure - 0.500
$\overline{X}$	49.0	
σ	5.1	

* Double Origin



(8-36309) (a)



(8-36308) (b)

Figure 10. (a) Typical longitudinal microstructures of compressor blades used for fatigue testing. (b) Typical for blade S/N 7, 71 and 78. Keller's Etchant (Magn: 500X)

2.6 Microstructure (Cont'd)

groups, S/N 7, 71 and 78, showed equiaxed alpha grains with dispersed alpha-beta regions indicative of hot working below the beta-transus temperature (Figure 10b). The below beta transus structure blades, were the lowest fatigue strength blades in each group.

3.0 CREEP STUDIES

Kramer and Balasubramanian[4] have shown significant reductions in the secondary creep rates of annealed Ti 6Al-4V, Type 321 stainless steel and cobalt base alloy Haynes 188, due to prestress-surface stress removal treatments. Figure 11 shows creep rate data on the three alloys as reported in Reference 4. All specimens were prestressed at their room temperature proportional limit, relaxed ~18 hours at the creep test temperature and then creep tested at various stress levels. The data indicate substantial reductions in creep rates when the creep stress is low compared to the proportional limit stress at the creep temperature. All three alloys show decreasing creep rate improvement as the creep stress approaches the proportional limit stress, where there is no improvement in creep behavior.

It would be desirable to reduce the creep rate of turbine blade alloys, which for the higher temperature stages are usually cast nickel base superalloys. A survey of the literature and discussions with Dr. I. Kramer revealed that the prestress/surface removal treatment has not been investigated on nickel base, gamma prime strengthened materials. Therefore, it was decided to investigate the treatment on test bars of a typical nickel base cast turbine blade alloy before proceeding on work with simulated hollow airfoil castings. Cast-to-size 1/4 inch diameter solid test bars of MAR-M246 alloy were chosen for this preliminary study. The composition of the test bar material is given in Table VI.

Table VI

Chemical Composition of MAR-M246 Cast Test Bars

C	Si	Mn	Cr	Mo	Fe	Ti	Al	Co	W	Cu	Zr
.15	.03	<.02	9.00	2.56	.10	1.62	5.62	10.22	9.39	.02	.07

B	Ta	Ni
.018	1.42	Bal

All bars were solution heat treated at 2225°F in vacuum for 1 hour and furnace cooled to room temperature prior to testing.

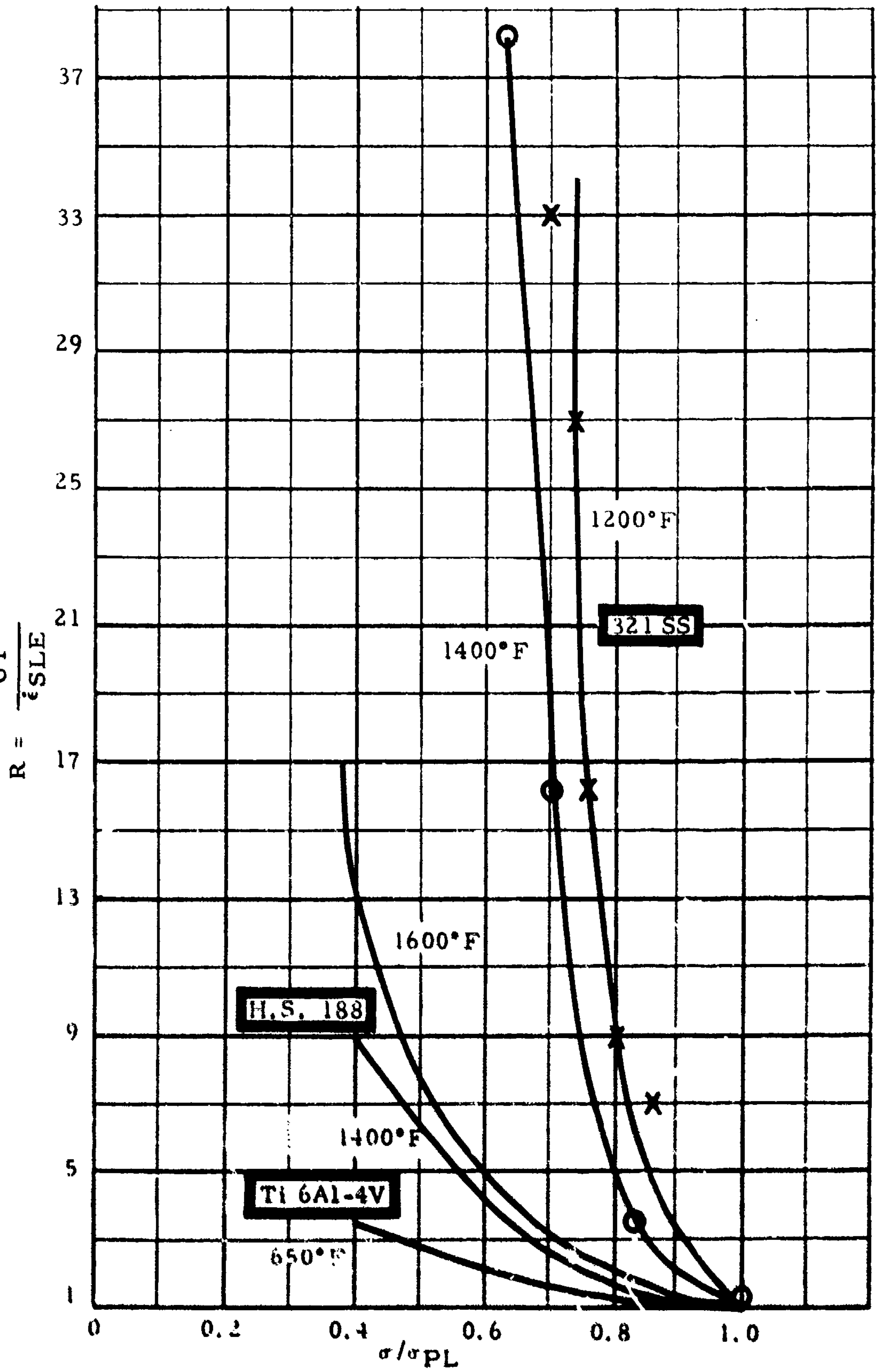


Figure 11. Ratio (R) of creep rates in untreated ($\dot{\epsilon}_{UT}$) and treated ($\dot{\epsilon}_{SLE}$) specimens as a function of creep stress (σ) and proportional limit stress (σ_{PL}) ratio. (Data from Reference 4)

3.1 Prestress/Surface Stress Removal

Prestressing of the cast-to-size MAR-M246 test bars was accomplished by axially loading the 1/4 inch diameter, 1 inch gage length through threaded bar ends in a tensile machine at room temperature. All bars for prestress treatment were stressed to the proportional limit of MAR-M246 (63 ksi at room temperature) after heat treatment. Stress strain curves obtained during prestressing of test bars verified that the proportional limit was not exceeded.

Surface stress removal was accomplished by thermal stress relaxation during a 1 hour hold at the creep test temperature prior to applying the creep load. One set of bars was subjected to chemical machining to remove the surface stress layer. A total of 0.005 inch was removed from the surface of the reduced section (0.010 inch on the diameter) in the following solution:

$FeCl_3$	40 mg
HCl	40 ml
HNO_3	40 ml
H_3PO_4	10 ml
H_2O	25 ml
Temperature	150-175°F
Time	2 hours

3.2 Creep Tests

Creep tests were conducted in 20:1 lever arm deadweight loaded creep machines, with creep strain measured by means of an LVDT extensometer clamped to recesses in the shoulders of the specimen. Creep strains were recorded on a multipoint strain-time recorder. The 1.25 inch straight section of the test bar was used as the gage length in calculating percent creep strain.

Three MAR-M246 1/4 inch diameter cast-to-size test bars from TRW Heat No. G4694 were selected for this preliminary investigation on the basis of concentricity in the as-cast condition and on the basis of uniformity of surface grain size. The test bars were heat treated at 2225°F ±25, (above the gamma prime solvus) for one hour in vacuum and furnace cooled to below

3.2 Creep Tests (Continued)

1000°F. Proportional limit in this heat treat condition was determined to be 63 ksi at room temperature. One bar was prestressed at room temperature at 63 ksi and a second, at 90 ksi. The third bar was not prestressed. All three were heated to 1850°F in a creep-rupture furnace, held for one hour to permit surface relaxation of the prestressed bars, and creep tested for 24 hours at 1850°F and 19 ksi. Examination of the creep curves did not show any significant differences in creep rates for three specimens as shown in Figure 12.

The three bars were re-solution treated at 2225°F as before and two of the bars retested. The bar previously tested without prestress (F-1) was prestressed at 63 ksi and retested, while the bar previously prestressed at 63 ksi (L-1) was creep tested without prestress. These bars were re-identified as F-2 and L-2, respectively. Both bars were heated to 1850°F in a creep rupture furnace held for one hour to permit surface relaxation of the prestressed bar, and creep tested for 24 hours at 1850°F and 19 ksi. Again, no significant differences in creep rates were observed, as shown in Figure 12.

In all of the above creep tests, the removal of surface stresses was hopefully accomplished by relaxation at 1850°F for one hour prior to creep testing. It is possible that complete stress relaxation did not occur and therefore no significant effect of prestressing. In order to insure surface stress removal on a prestressed specimen, bar L-2 was resolution treated, prestressed at 63 ksi, chemically machined to remove 0.005 in. from the reduced section surface of the test bar, and creep tested as before. Bar F-2 was similarly reprocessed and tested, but without prestress. These bars were re-identified as L-3 and F-3, respectively. The creep rates at 1850°F and 19 ksi for these two bars were not significantly different.

Secondary creep rates were calculated for all of the creep tests performed to date on MAR-M246 and are shown in Table VII. A review of these test data does not show any significant lowering of the secondary creep rate for MAR-M246 due to prestressing/surface removal treatments.

A review was made to determine relationship between the room temperature proportional limit stress of MAR-M246 and the prestress used in these tests, as well as between the 1850°F proportional limit and creep stress used. Figure 13 shows the proportional limit stress of cast-to-size 0.250 inch diameter test bars of MAR-M246. The room temperature proportional limit ranges from 63-72 ksi compared to a 63 ksi prestress. The

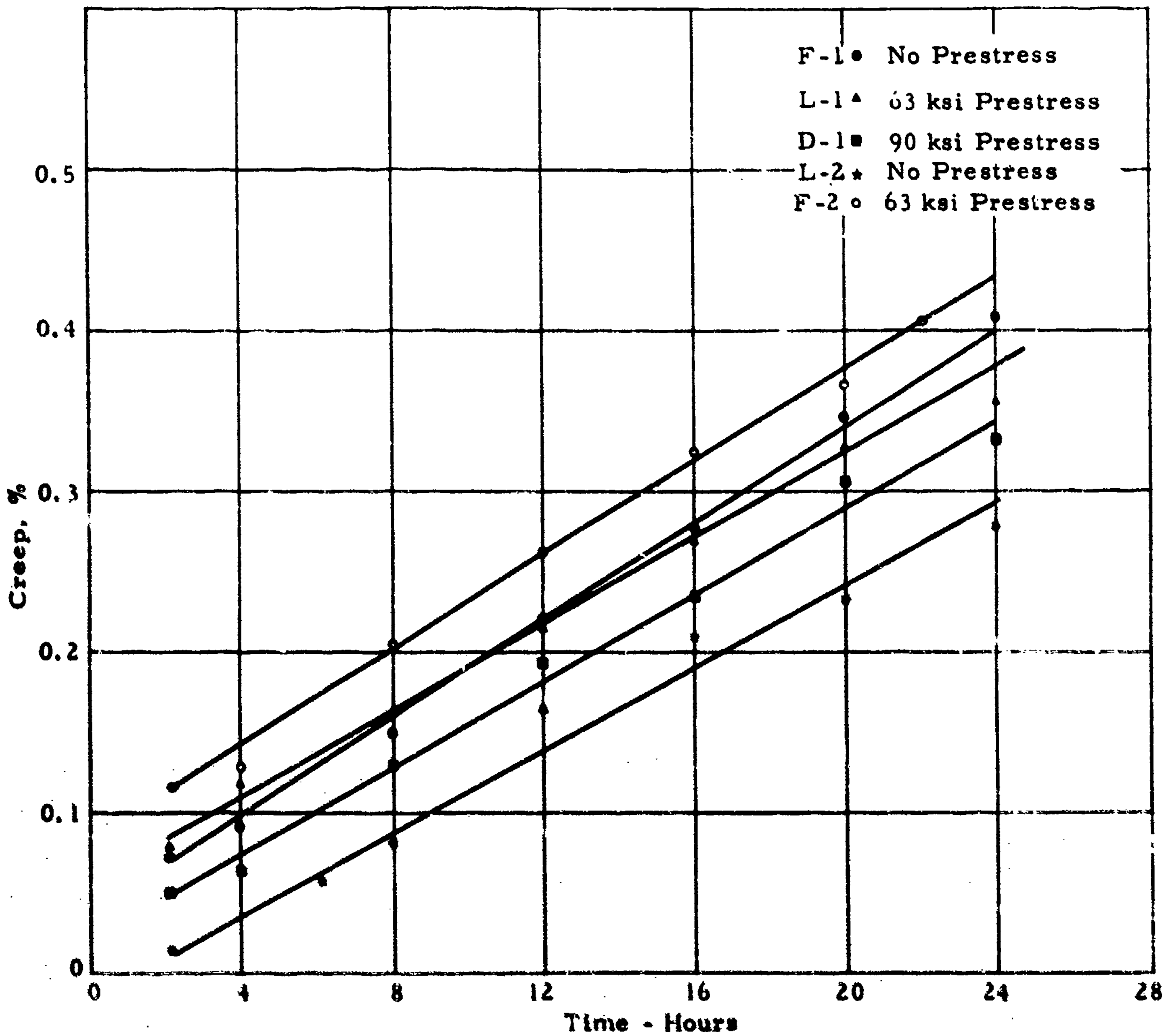


Figure 12. Creep curves for MAR-M246, 1850°F - 19 ksi.

Table VII

Effect of Prestress/Surface Removal Treatment on Secondary Creep Rate of MAR-M246(1)

Specimen No.	Prestress ksi	Surface Stress Removal	1850°F - 19 ksi Creep Rate - (10^{-4} per hour)
F-1	None	Thermal	1.50
L-1	63	1850°F-1 hr	1.33
D-1	90		1.35
F-2	63	Thermal	1.46
L-2	None	1850°F-1 hr	1.19
F-3	None	Chemical - .005"	1.29
L-3	63	from Surface	1.25

(1) Cast .250 inch diameter bars, vacuum annealed 2225°F - 1 hr - furnace cooled.

Detroit Diesel Allison
Division of General Motors Corporation
Indianapolis, Indiana 46206

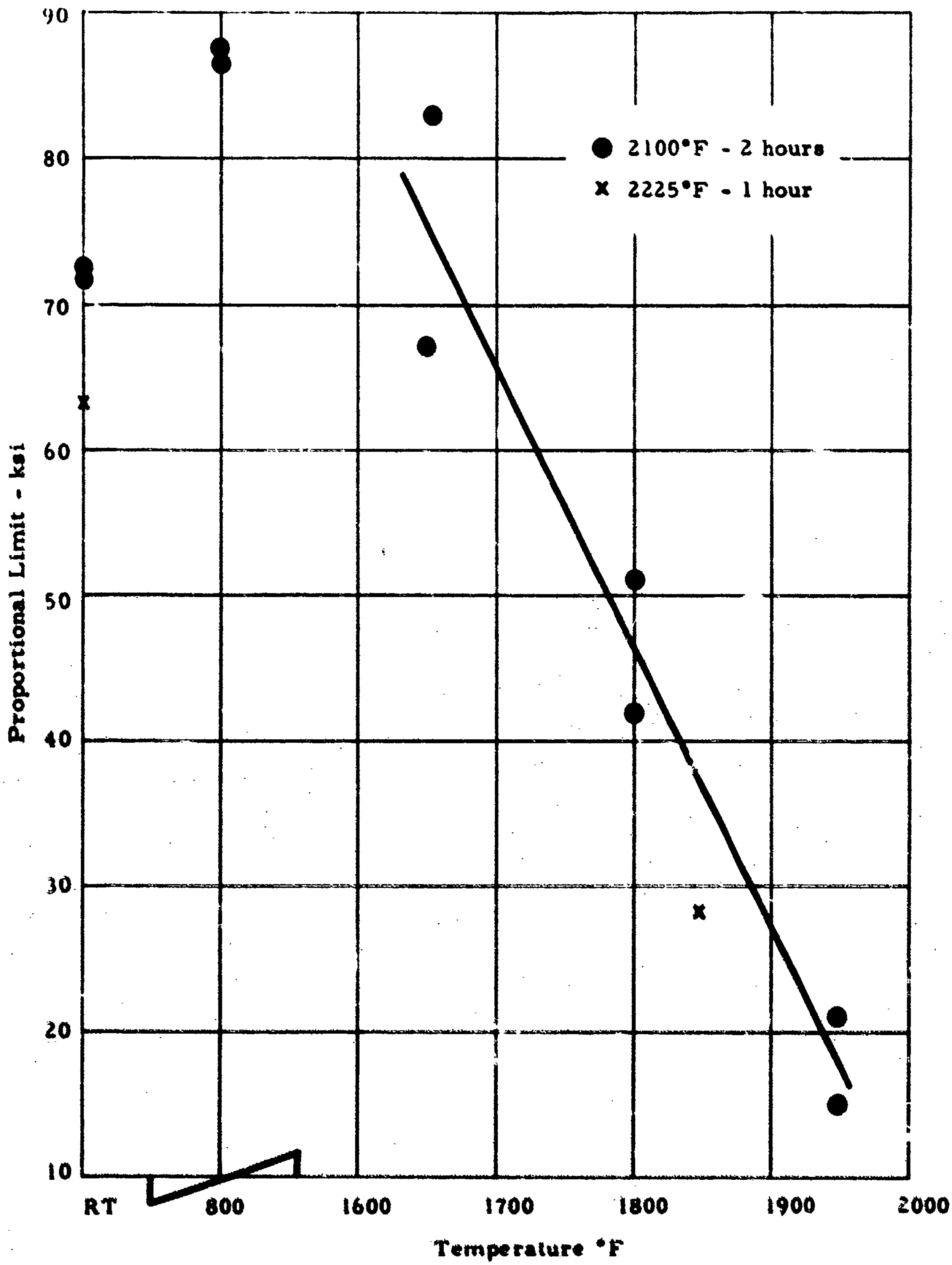


Figure 13. Elevated temperature tensile proportional limit stress of MAR-M246 cast bars.

3.2 Creep Tests (Continued)

1850°F proportional limit ranges from 28-37 ksi compared to a creep stress of 19 ksi. Using the lower proportional limit values which were obtained on bars heat treated in the same manner as the creep bars, the prestress level was 100% of the room temperature proportional limit and the creep stress was 68% of the 1850°F proportional limit. Based on prestress/surface stress removal treatments and subsequent creep tests[4] on other alloys, such as Ti 6Al-4V, Type 321 stainless steel and Haynes 188 alloy, prestressing at the room temperature proportional limit, removing surface stress, and creep testing at 68% of the creep temperature proportional limit, should have produced a substantial reduction in secondary creep rate in MAR-M246. Since none of the creep tests conducted showed an effect on the creep rate, we conclude that prestress/surface removal treatment is not effective on creep rate reduction of MAR-M246, at least under realistic turbine blade temperature and stress. It may also be true that it is not effective in this class of alloy — namely, gamma prime strengthened nickel base superalloys.

3.3 Microstructure

The microstructure of the MAR-M246 test bars used in the creep tests is shown in Figure 14. The structures are typical for the alloy with gamma prime $Ni_3(Ti,Al)$ precipitate within the grains and complex carbides in the grains and grain boundaries.

(8-36314) (Magn. 100X)

(8-36311) (Magn. 500X)

Figure 14. Typical microstructure of MAR-M246 test bars used in creep tests. Etchant: Marble's Reagent

4.0 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are made from the work performed in this program:

(a) Prestressing annealed Ti 6Al-4V compressor blades at 80-100 ksi and stress relaxing at ambient temperature for >100 hours, improves the average 10^7 cycle bending fatigue strength up to 60%.

(b) Glass bead peening was not effective in improving the 10^7 cycle fatigue strength of the annealed blades.

(c) A practical method for prestressing blades must be developed before this process could be applied to production hardware.

(d) It is recommended that additional fatigue tests be conducted on a different blade geometry, wherein the fatigue failures originate in the airfoil, away from the notch effect of radii, and the prestress and fatigue stresses can be more accurately measured.

(e) The prestress-surface stress removal treatment is not effective in reducing the secondary creep rate of MAR-M246 cast nickel base alloy, at least under realistic turbine blade temperature and stress conditions. It also may not be effective for this class of alloy — namely, gamma prime strengthened nickel base superalloys.

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(e) The prestress-surface stress removal treatment is not effective in reducing the secondary creep rate of MAR-M246 cast nickel base alloy, at least under realistic turbine blade temperature and stress conditions. It also may not be effective for this class of alloy — namely, gamma prime strengthened nickel base superalloys.

5.0 REFERENCES

(1) I. R. Kramer and A. Kumar, "Study of the Effects of Diffused Layers on the Fatigue Strengths of Commercial Titanium Alloys", Technical Report AFML-TR-70-185, September 1970.

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(3) I. R. Kramer and N. Balasubramanian, "Enhancement of the Creep Resistance of Metals", Final Report NASC Contract N00019-71-C-0143, September 1971.

(4) I. R. Kramer and N. Balasubramanian, "Enhancement of Creep Resistance of Metals", Metallurgical Transactions, Vol. 4 No. 2, pp. 431-436, Feb. 1973.